coats. Thick runs and streaks must be avoided, particularly on gasket seating surfaces where they may chip off and leave uneven surfaces that will interfere with proper sealing of the filter. After painting, gasket seating surfaces should be coated with a silicone oil or grease to prevent the filter gasket from adhering to the paint after a period of service. Clamping bolts should not be painted because the paint will scrape off and jam the nuts. Threads should be masked during painting and then coated with silicone grease.

High-build epoxy-polyamide and modified phenolic coating systems have proven satisfactory for interior steel and masonry surfaces. Although inorganic zinc primers are often recommended for steel, their use is not recommended for housing interiors because the zinc particles are difficult to hold in suspension properly and they tend to surface, causing blistering and peeling of the top coats.[26] An airless spray is recommended for applying prime and top coats. Guidance for selecting coatings and paints for nuclear service is given in ANSI N512.[27] For selection purposes, the classification "moderate exposure" is recommended for high-activity (or potential high-activity) systems, and the classification "light exposure" is recommended for low-activity systems. The recommendations on quality assurance during application of paints and coatings given in ANSI N101.4[28] are suggested for Engineered Safety Feature (ESF) and other high-activity (or potential high-activity) systems.

Inorganic zinc primers are acceptable for exterior steel surfaces, but complete curing may take from two days to six weeks, depending on temperature and humidity conditions. One or two coats of high-build epoxy, vinyl, acrylic, or silicone paint are recommended for exterior steel surfaces exposed to the weather. Epoxy-polyamide coatings arc superior to epoxy amines for water and salt resistance and have better tolerance for moisture during application. Vinyls are excellent for general marine and chemical plant exposures and do not chalk as much as epoxies when exposed to sunlight. On the other hand, they are inferior to epoxies in abrasion resistance, solvent resistance, and resistance to severe water or brine splashing. For outdoor service, acrylic coatings give the best protection against chalking and discoloration from sunlight and ultraviolet, but are suitable only as topcoats over an intermediate epoxy or vinyl coating. Silicone-based paints are useful for high-temperature applications, and aluminum-filled silicones give good protection up to 1,000 degrees Fahrenheit (537.8 degrees Celsius). For a housing or duct that is located indoors and is exposed only to normal building atmospheres, an acrylic paint is suitable and gives good protection against color fading.

Because of difficulties in applying high-quality coatings and their often-unsatisfactory performance, the designer should seriously consider stainless steel for mounting frames and housings in applications where corrosion or frequent decontamination will be encountered. Although quoted prices for carbon steel construction with high-quality coating systems generally run about 20 to 25 percent of the cost of stainless steel construction, experience shows that delays and difficulties in proper application frequently raise the final cost of coated carbon steel to as much as or more than stainless steel. Further references for painting include ASTM D3912,[29] D3911,[30] D3843,[31] and N101.2.[32]

4.4 MAN ENTRY HOUSING

4.4.1 GENERAL

Steel man-entry housings may be shop-built or field-fabricated. The trend, particularly in ESF systems, is increasingly toward shop-built steel housings. Stainless steel is the most common material of construction; however, carbon steel also may be used. Aluminum and galvanized steel are not suitable.

4.4.2 STRUCTURAL

The mounting frame is a statically indeterminate lattice that generally consists of a set of full-length members spanning the height or width of the bank (whichever is shorter), connected by cross members that are slightly shorter than the width of individual filter (adsorber) units. For design purposes, the frame may be considered as an array of simply supported, uniformly loaded beams. Experience has shown that, to obtain adequate frame rigidity, these beams (frame members) should deflect no more than 0.1 percent of their length under a loading equivalent to 1.5 times the maximum dirty filter pressure drop across the bank. This loading is determined from the following equation.

$$W = 0.036(1.5)\ \hat{\mathrm{I}}p\ S, \tag{4.1}$$

Where

0.036 = conversion factor, in.wg to psi

W = uniform beam loading, lb/in.

$\hat{\mathrm{I}}p$ = pressure drop across bank, in.wg

S = center-to-center spacing of filters on bank, in.

Assuming a center-to-center spacing of 26 in. for 24- by 24-in. filters, Equation (4.1) reduces to:

$$W = 1{,}404\ \hat{\mathrm{I}}p \tag{4.2}$$

The value determined from Equation (4.2) can be used in standard beam equations[8] to determine the minimum moment of inertia required. Knowing the minimum moment of inertia required for the member, the size and shape can be selected directly from the tables of structural shape properties given in the AISC *Manual of Steel Construction*.[9] It can also be determined by calculating the moment of inertia of a built-up or cold-formed section. For ASTM A36 steel, the standard beam equation reduces to the following equations.[2]

Major frame members, $$I = \frac{\hat{\mathrm{I}}p\ L^3}{1.59 \times 10^6} \tag{4.3}$$

Cross-members, $$I = \frac{\hat{\mathrm{I}}p}{149} \tag{4.4}$$

Where

I = minimum moment of inertia required, in.^{4}

$\hat{\mathrm{I}}p$ = maximum dirty-filter pressure drop across bank, in.wg

L = length of member, in. (cross-members assumed to be 22 in. long)

In addition to flexural strength, the frame for an exhaust or air cleanup filter system should also be capable of withstanding a shock loading of at least 3 psi across the bank without exceeding the elastic limit of the frame material. In most cases, members calculated using Equations (4.3) and (4.4) will meet this requirement; nevertheless, they should be checked. The section moduli (S values) given in Part I of the AISC *Manual of Steel Construction*[9] then should be compared with the minimum values obtained from the following equations.

Major frame members, $$S = \frac{13L^2}{f_a} \tag{4.5}$$

Cross $$S = \frac{6290}{f_a} \tag{4.6}$$

Where

S = section modulus, in.^{3}

f_a = maximum allowable fiber stress, psi

L = length of member, in. (cross-members assumed to be 22 in. long)

For ASTM A36 steel, these equations reduce to

Major frame members, $$S = 0.00361L^2 \tag{4.7}$$

Cross-members, $$S = 0.175 \tag{4.8}$$

For built-up and cold-formed members, the minimum S value calculated from these expressions is compared with the value for the member calculated from the formula.

$$S = \frac{I}{c} \tag{4.9}$$

Where

S = section modulus, in.^{3}

I = moment of inertia of the section, in.^{4}

c = distance from neutral axis of member to extreme fiber, in.

If the S values obtained from the AISC manual or calculated by using Equation (4.9) are greater than the values calculated from Equations (4.5) through (4.8) (as applicable), the members selected are satisfactory.

4.4.3 STRUCTURAL DESIGN

Structural design of housings for both ESF air cleaning units and non-ESF units must consider the service conditions the housing may experience during normal, abnormal, and accident plant conditions. The design requirements for determining housing plate thickness, stiffness, spacing, and size is presented in the ASME Code on Nuclear Air and Gas Treatment, ASME AG-1.[26]

Housing design should consider the following load criteria.

- Additional dynamic loads
- Constraint of free end displacement Loads
- Dead weight
- Design pressure differential
- Design wind
- External loads
- Fluid momentum loads
- Live load
- Normal loads
- Normal operating pressure differential
- Seismic load
- System operational pressure transient

Stress criteria limits are given in ASME AG-1, Section AA-4000.[26] The maximum deflection for panels, flanges, and stiffeners for the load combination should be the lesser of the two values derived as shown below.[1]

Criterion 1

- Plate or sheet: 1/8-in. per ft of the maximum unsupported panel span in direction of airflow, but not more than 3/4-in.
- Stiffeners and flange connections: not to exceed 1/8-in. per ft of span, but not more than 3/4-in.
- Flange connection to dampers and fans: 1/360th of the span, but not to exceed 1/8-in.

Criterion 2

Deflections shall be limited to values that will not cause:

- Distortion of the airflow path cross-section, resulting in unacceptable increase in system pressure
- Damage to safety-related items such as instrumentation or other safety-related equipment or accessories
- Impingement of deflected elements on adjacent services such as equipment, pipe, cables, tubing, etc.
- Loss of leaktightness (in excess of leakage limit)
- Buckling (Refer to ASME AG-1, Section AA-4000)[26]
- Functional failure of components attached to ductwork (e.g., instrument lines, etc.)

4.4.4 Mounting Frame Configuration

The basic type of mounting frame construction is face-sealed, i.e., the filter seals to the outermost surfaces of the frame members by means of gaskets glued to the front surface or to the flange around the face of the filter unit, as shown in **FIGURE 4.15**. The face-sealed configuration is generally recommended for conventional-design HEPA filters and Type I adsorber cells.[10]

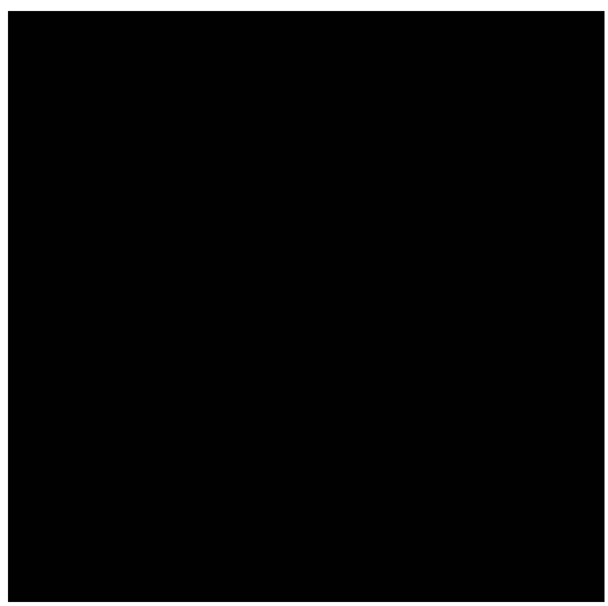

Figure 4.15 – Filter gasket seals against mounting frame face plate

A minimum face width of 4 in. is recommended for major and cross members of face-sealed HEPA filter frames. This allows 1-in.-wide filter-seating surfaces to compensate for any misalignment of the filter during installation and a 2-in. space between filters, horizontally and vertically. It also provides adequate room for handling (personnel replacing contaminated filters will probably have to wear double gloves), using power tools or torque wrenches during filter change, and manipulating a test probe between units.

Face-widths of frame members for installing Type I (pleated-bed) adsorber cells are the same as those for HEPA filters. Face-widths of frame members for installing Type II (tray-type) adsorber cells may be narrower, since handles are provided on the front of the trays to facilitate installation. To provide interchangeability for cells of different manufacture, IES CS-8 recommends the following mounting frame dimensions for the installation of Type II cells (see IES CS-8 for standard cell dimensions):[10]

- Openings: 6.37 by 24.188 in. (+0.063 in., -0 in.)
- Space between openings: vertical, 2.5 in. minimum; horizontal, 2 in. minimum

FIGURES 4.16 and 4.17 show a built-up all-welded Type II adsorber cell mounting frame made from rectangular structural tubing; note that a structure is required behind the frame openings to support the weight of the cells (approximately 100 lb each). Because the length of Type II cells may be different for each manufacturer, the support structure should be deep enough to take a cell up to 32 in. long to permit interchangeability of cells of different manufacture.

Figure 4.16 – Absorber tray mounting frame. "X" cross units are for test gas injection

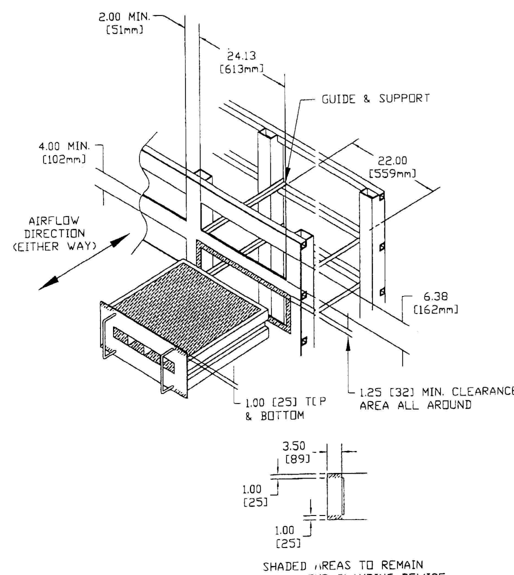

Figure 4.17 – Absorber mounting frame with carbon trays

Table 4.1 – Minimum-Cost Structural Members for 24 by 24 HEPA Filter and Type I Adsorber Mounting Frames (maximum pressure drop to 12 in.wg)

	Principal member[a] I-beam			Cross-member channel (span = 22 in.)	
No. of 1,000 cfm units high	**Span [b]**	**Size (in.)**	**lb/ft**	**Size (in.)**	**lb/ft**
2	4 ft 8 in.	4 × 4 M	13	4 × 1¾	5.4
3	6 ft 10 in.	4 × 4 M	13	4 × 1¾	5.4
4	9 ft 0 in.	4 × 4 M	13	4 × 1¾	5.4
6	13 ft 4 in.	6 × 4 B	16	4 × 1¾	5.4
8	17 ft 8 in.	8 × 4 B	10	4 × 1¾	5.4
10	22 ft 0 in.	10 × 4 5/8	25.4	4 × 1¾	5.4

[a]Principal members should span the shortest dimension of the bank.

[b]Span = [(number of filters) (26) = 4 in.]

Note: This table is intended to provide information only. The designer is responsible for verifying this information.

Satisfactory mounting frames may be made from rolled structural shapes or rectangular structural tubing. **FIGURE 4.20** shows a HEPA filter frame made from 4- by 4-in. structural tubing that meets all structural requirements. Rolled structural shapes for building mounting frames are given in **TABLE 4.1**. Square structural tubing frames for HEPA filters should be made from rectangular tubing with a face width of at least 4 in.; structural tubing frames for Type II adsorber cells may have narrower face widths.

4.4.5 Frame Fabrication – Gasket-Type Filter/Adsorber

Filter mounting frames should be shop-fabricated as practicable because it is nearly impossible to avoid misalignment, warping, and distortion in field fabrication. Shop fabrication is less costly than field fabrication and permits better control over assembly, welding, and dimensional tolerances. Care must be taken to avoid twisting or bending the completed frame during handling, shipping, and field installation. For proper performance and maintenance of installed filters, dimensional and surface-finish tolerances must be tight and rigidly enforced. **TABLE 4.2** gives minimum tolerances for the installed frame. Welds on the filter-seating side of the frame must be ground flat, smooth, and flush.

Table 4.2. Recommended Tolerances for HEPA Filter and Adsorber Mounting Frames

Alignment	Perpendicularity: maximum offset of adjoining members 1/64-in./ft or 1/16-in., whichever is greater. Planarity of adjoining members: 1/64-in. maximum offset at any point on the joint.
Flatness	Each filter surface shall be plane within 1/16-in. total allowance. Entire mounting fixture shall be plane within 1/2-in. total allowance in any 8- by 8-ft area.
Dimensions	Length and spacing of members shall be true within +0, -1/16-in.
Surface finish	Filter seating surfaces are 125 μin. AA maximum, in accordance with USA Standard B46.1; pits, roll scratches, weld spatter, and other surface defects shall be ground smooth after welding, and ground areas shall merge smoothly with the surrounding base metal; waviness not exceeding 1/32-in. in 6-in. is permissible as long as the overall flatness tolerance is not exceeded.
Note: This table is intended to provide information only. The designer is responsible for verifying this information.	

Only welders qualified in accordance with the AWS D1.1, *Structural Welding Code-Steel*[22] or Section IX of the *ASME Boiler and Pressure Vessel Code* [12] should be permitted to make welds on HEPA filter and adsorber mounting frames. Both seal and strength welds should be visually inspected by a qualified inspector under a light level of at least 100 ft-c on the surface being inspected. In addition, liquid penetrant (ASTM E165[33]) or magnetic particle inspection (whichever is applicable for the base material being inspected) of the seal welds between frame members is recommended.

4.4.6 FILTER CLAMPING AND SEALING

HEPA filters and adsorber cells must be carefully sealed to the mounting frame to achieve the required low penetration leakage rates and to allow easy replacement. Except for the fluid-seat design described at the end of this section, sealants are not a satisfactory substitute for gaskets. Experience in clean rooms and contaminated exhaust and air cleanup applications has shown that flat, closed-cell, neoprene gaskets, ASTM D1056 grade 2C3,[14] give the most satisfactory seal for high-efficiency filters, adsorbers, and demisters. There is no advantage in using shaped (molded) gaskets; not only are they more expensive, but research has shown that they are prone to leaks.[15, 16] Gaskets that are too soft (i.e., are less than grade 2C3) take an excessive compression set that may permit leakage when there is relaxation of the clamping bolts. Gaskets that are too hard (i.e., harder than grade 2C4) require such high clamping loads to effect proper scaling that the filter itself can be distorted or damaged.

As little as 20 percent gasket compression is needed to effect a reliable seal when the thickness of the gasket is uniform to within ±0.01 in. and the seating surface of the mounting frame is plane to within ±0.01 in.[16] However, these tolerances are much too restrictive for economical construction, and experience has shown that it is usually necessary to compress a 2C3 gasket at least 80 percent to effect a reliable seal over long periods. Eighty-percent compression requires a loading of approximately 20 lb per square in. of gasket area or a total clamping load of about 1,400 lb for a 24- by 24-in. filter unit. The recommended procedure for installing filters is to initially torque the clamping bolts to produce 50 percent gasket compression and then retorque them one or two weeks later to a total compression of about 80 percent. (**FIGURES 4.18, 4.19, and 4.20**). In a

Figure 4.18 – Filter hold-down clamp

Figure 4.19 – Filter hold-down clamp

radioactively contaminated filter system, replacement can be a hazard to personnel and to the filters and/or adsorbers installed in the system. A spring-loaded hold-down is an option used at some U.S. Department of Energy (DOE) sites where the system is contaminated; this design requires one entry (**FIGURE 4.26**). Torsion bar clamps designed to exert the proper clamping forces are another option.

Gaskets that are too thin may not give a reliable seal using the recommended frame tolerances given in TABLE 4.2, whereas those that are too thick may be unstable and tend to roll or pull off the flange of the filter case as they are compressed, perhaps to the extent that sections may be extruded between the case and mounting frame and produce a serious air leak. Recommended gasket sizes are 1/4- to 3/8-in. thick by 3/4-in. wide and 1/4- to 3/8-in. thick by 5/8-in. wide. Gaskets must be glued to the filter element rather than to the mounting frame because they must be replaced with each filter change. A sealant such as silicone should not be applied to the filter frame because it must be removed before installing new filters and the sealant may be contaminated, making disposal more difficult. Gaskets should have cut surfaces on both faces because the "natural skin" produced by molding sometimes tends to bridge discontinuities or defects in the seating surface, and because the silicone mold-release compounds used in the manufacture of sheet